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# Ethics and acceptance of smart homes for older adults

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## ABSTRACT

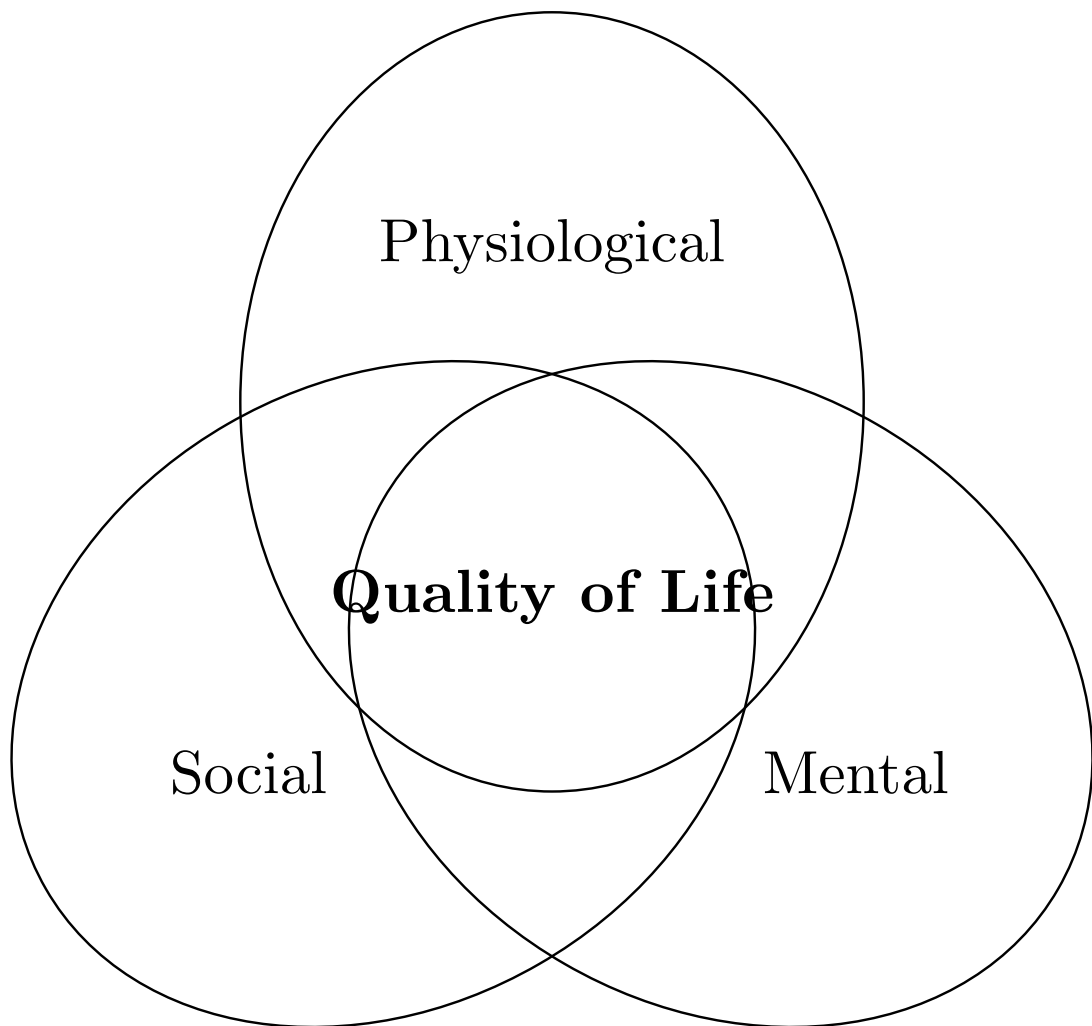
Societal challenges associated with caring for the physical and mental health of older adults worldwide have grown at an unprecedented pace, increasing demand for health-care services and technologies. Despite the development of several assistive systems tailored to older adults, the rate of adoption of health technologies is low. This review discusses the ethical and acceptability challenges resulting in low adoption of health technologies specifically focused on smart homes for older adults. The findings have been structured in two categories: Ethical Considerations (Privacy, Social Support, and Autonomy) and Technology Aspects (User Context, Usability, and Training). The findings conclude that older adults community is more likely to adopt assistive systems when four key criteria are met. The technology should: be personalized toward their needs, protect their dignity and independence, provide user control, and not be isolating. Finally, we recommend researchers and developers working on assistive systems to: (1) provide interfaces via smart devices to control and configure the monitoring system with feedback for the user, (2) include various sensors/devices to architect a smart home solution in a way that is easy to integrate in daily life, and (3) define policies about data ownership.

## KEYWORDS

Ethics; smart home; ambient-assisted living; assistive technology; ethical aspects

## Introduction

Globally, in 2010, it was estimated that 524 million people were over 65 years old which was approximately 8% of the world population. The World Health Organization (WHO) has estimated this number to grow to 1.5 billion by 2050, making it approximately 16% of the world's population.<sup>4</sup> Further, for some countries, the population growth in this demographic is even more dramatic: in the UK alone, in mid-2017, the age group 65 and above was 18.2% of the total population and this was then estimated to grow to 20.7% by 2027, with projections for a further increase to 26.5% by 2040.<sup>12</sup> This demographic shift toward an aging population increases health challenges, giving rise to a need for health-care technologies targeted to help an aging population. There is an increase in people living with complex chronic illnesses. Globally, around 50 million people have dementia, and there are nearly 10 million new cases every year with significant costs to health services,<sup>5</sup> while, in the UK, dementia costs GBP 26.3 billion per year averaging at GBP 32,250 per patient per year, including health and social care (public and private funded). In addition, between GBP 22.1 and GBP 40.3 million per year is spent on police costs for missing people with dementia.<sup>6</sup> More recently, due to COVID-19, additional health-care challenges have arisen for older adults<sup>7</sup> as they are at much higher risk due to the virus.<sup>8</sup> The number of deaths was highest among this demographic, specifically those who were aged 80 or above.<sup>7</sup> According to ONS, the death rate was higher in males over the majority of age groups.<sup>7</sup> The significant increase in at home deaths triggered by the pandemic



**Figure 1.** Conceptual design of characteristics of health related QoL.

highlights the need for better health-care monitoring with remote communication features to be able to connect older adults with family members or emergency services in the time of need.

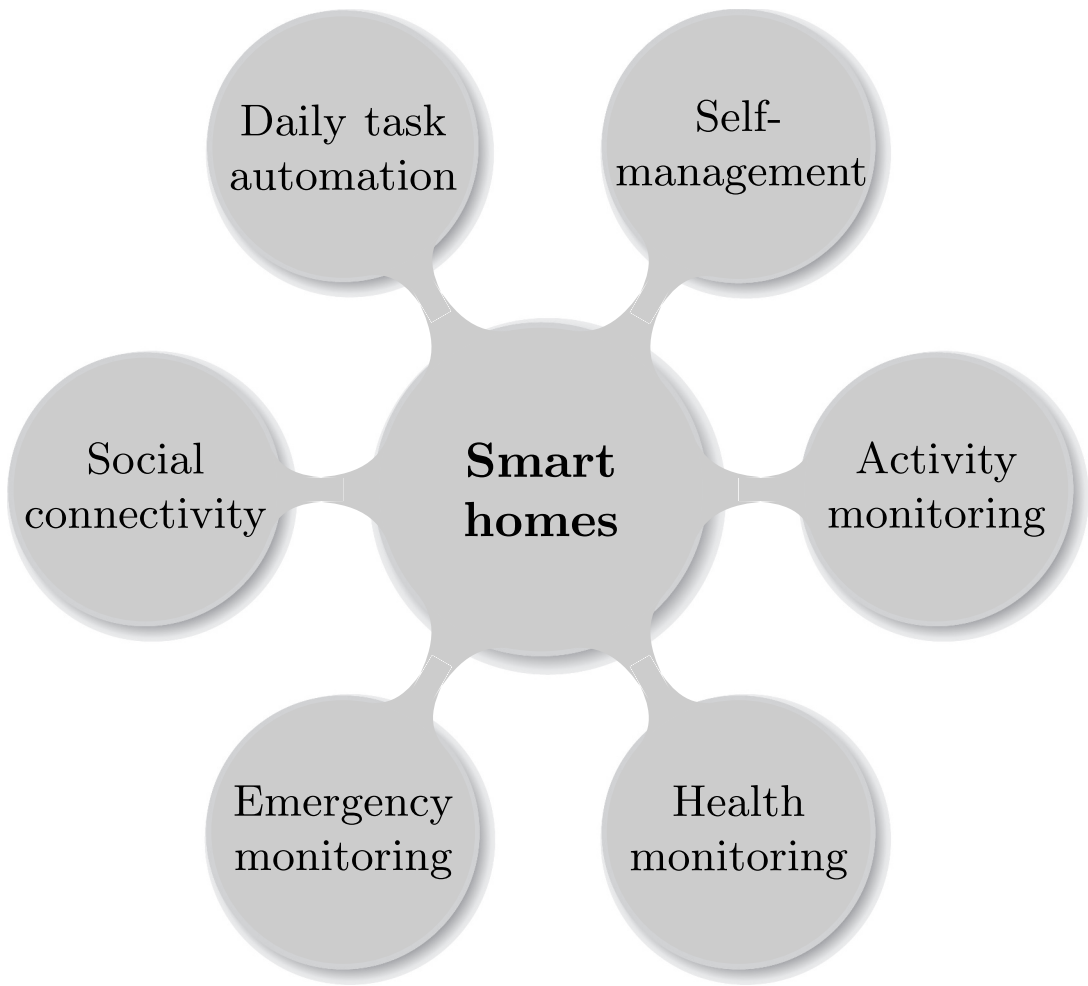
To reduce this pressure, assistive technologies are being researched and developed for older adults to enable them to lead their daily lives independently without compromising their health and safety. Advanced technologies benefit families and caretakers offering affordable options to monitor, care and provide safety to their loved ones remotely.

In other words, the purpose of these technologies is to assist people of advanced age in their daily lives to achieve a good quality of life (QoL). QoL is characterized by various factors, such as social contacts, activities,

health and family relations,<sup>9</sup> and therefore the World Health Organization (WHO) characterizes health-related QoL as physiological, social and mental well-being,<sup>1</sup> as illustrated in [Figure 1](#).

Within this paper, we define a *smart home* as a home with a system consisting of one or several assistive technologies. We are focusing on the use of these technologies to improve QoL for the aging community, for example, using assistive technologies to ease the activities of daily life, health

<sup>1</sup>World Health Organization, WHOQOL: Measuring Quality of Life. <https://www.who.int/healthinfo/survey/whoqol-qualityoflife/en/>



**Figure 2.** Functionalities of a smart home.

monitoring, and self-management systems to help with recording physiological details, fitness-related technologies to be physically active and track emergency situations such as falls. [Figure 2](#) illustrates the functionalities of a smart home to provide various benefits to older adults. There is continuous research and development on functionalities of smart homes.<sup>10–14</sup> One of the main concerns is the adoption and acceptance of these technologies. The number of studies conducted for the acceptance and adoption for smart home technologies for health-care targeting older adults is surprisingly low. In this paper, we present a literature review about the acceptability and ethical issues surrounding smart home technologies for the aging community, addressing the possible issues and challenges.

### **Motivation and goals**

Smart home technologies provide several benefits in terms of supporting a good QoL for older adults. Despite the continuous research and development and the availability of several products in the market, questions arise regarding the technology acceptance, adoption, and interaction.<sup>3</sup> This could be due to several reasons, such as age, gender, health status, physiological and cognitive abilities all of which can heavily impact the acceptance and adoption of assistive technologies.<sup>15</sup> Another reason for low adoption could be related to the system design not adapting to ethical concerns, user experience,

user interaction, awareness about technology, or catering for individual user requirements and/or personalization.

A recent study in the U.S. found that there is a rise in the adoption rate of certain smart home technologies among older adults, which include water leak detectors, thermostats, carbon monoxide alarms, smartphones, and back-up generators. The older population in the study was reluctant to adopt novel technologies and did not prefer smart home technologies, such as remote home monitoring, voice assistant systems, camera motion activated systems, and smart lights.<sup>16</sup> An earlier study in 2005, Lau studied the adoption rate of personal emergency response services (PERS) in various countries.<sup>17</sup> They stated that despite the availability of these technologies for some time in the market, only a fraction of the population adopted these technologies with less than 5% of aged Americans adopting PERS. In the UK, the adoption rate was only 15% and below 20% in other countries.<sup>17</sup> Another reason for this could be simply due to the lack of smart home assistive technologies readily available. Liu et al. found that readiness for smart home and health monitoring technologies is still low. Around 56% of the studies regarding smart homes and home health monitoring technologies were carried out or tested in lab environments and were proof of concepts. Currently, there is no evidence that these technologies help address cognitive decline, QoL, or heart conditions for older adults with complex needs.<sup>18</sup> Many research studies focus on using models available to investigate the acceptance of assistive technology among older adults but it is still unclear the reasons for low adoption of these technologies.<sup>19</sup>

Intelligent assistive technologies for dementia patients were found to be developed in the absence of ethical considerations which results in low prevalence.<sup>20</sup> While a further assistive technology study (BRAVEHEALTH) shows that participants had a positive attitude toward the technology but were still resistant to adopt the system due to concerns over reliability, security, privacy, and trust. For example, some preferred to engage personally with physicians rather than use videoconferencing.<sup>21</sup> Studies show that video conferencing is perceived useful with benefits such as convenience and time and cost efficiency.<sup>22–24</sup> It was found that most people had experience of using video conferencing for personal or work reasons but less than half people used it for health and rehabilitation reasons.<sup>23</sup> In another study, doctors and patients were willing to use videoconferencing, although they preferred face-to-face contact, subject to the nature of the complaint meaning VC is not a solution for all illness and clinical needs but more suitable for short visits with nonchronic conditions or in an urgent care setting.<sup>24</sup> In light of the recent COVID-19 pandemic, it is possible that attitudes around videoconferencing have further changed, especially as it has become a more normal activity in everyday life.

Hence, it is important to gain an understanding of the acceptability and adoption rate of the health-care technologies, especially for smart homes. The main goal of our research is to identify the reasons for this low adoption by conducting this literature review and find the methods by which adoption and acceptance can be increased. In the end, we offer some recommendations that may help shape the future assistive technologies to make them more acceptable.

## Methodology

To understand more about the low acceptance and adoption of the smart home technologies among older adults, we conducted a literature review. We searched in MedlinePlus, PubMed, IEEE Xplore, and Google Scholar using the following keywords: (“acceptance,” “adoption,” “perception,” “awareness,” “ethics,” and “ethical implications”) and (“elderly,” “elderly population,” and “older adults”) and (“assistive technology,” “intelligent environment,” “smart home,” “medical technology,” and “health technology”). We refined our search through the development of stringent inclusion and exclusion criteria (Table 1).

**Table 1.** Criteria for work to be included in this review.

Inclusion Criteria	Exclusion Criteria
Focused on older adults where certain studies also included younger age groups.	Studies conducted using robots as assistive technology.
Technologies related to smart homes	Smart homes not consisting of participants of advanced age.
Assistive technologies for self- management, easily integrable in daily life to promote independence.	Assistive technologies involved in hospitals or rehabilitation centers
Older adults living independently.	Research focusing on other aspects such as robots, sound, speech detection and security aspects of smart homes.
Studies were published in English	Articles that did not fit the inclusion criteria.
Studies about perception of smart home technology focusing on acceptance or adoption by older adults.	

**Acceptance models**

Research studies have used models to investigate the adoption and acceptance of a technology, one of which is named “The Technology Adoption Model/Technology Acceptance Model (TAM).” This model is based on perceived usefulness (PU) and perceived ease of use (PEU) where PU means the person perceiving the technology under investigation as useful and PEU refers to a person perceiving the technology is not complex to operate and therefore easy to use without a lot of effort.<sup>25</sup> In 2000, this model was extended as TAM2 which included two more factors which impact the acceptability of a technology. Social influence means a person’s perception toward a technology formed by family, friends or social status. While the latter means a person’s assessment of a technology based on how relevant it is for the goals, results and its level of quality along with its ease of use.<sup>26</sup> In 2003, the Unified Theory of Acceptance and Use of Technology was presented (UTAUT). This model merged contributions of various adoption theories and models of technology use.<sup>25,27–33</sup> This model was further extended to UTAUT2 to further include a user’s perspective considering cost, motivation and habits, for example.<sup>34</sup> Other models that talk about factors affecting adoption include Technology to Performance Chain Model (TPC) and Model of Acceptance of Technology in Households (MATH)<sup>35–37</sup> and Elderadopt.<sup>38</sup> Many researches have used these models which include.<sup>39–51</sup> Capability Approach Framework (CA) is designed to describe an individual’s use of resources to improve their daily life.<sup>52</sup> However, this model was used by Nikou et al., to investigate the adoption of digital health care technology among older adults.<sup>53</sup> The Expectation Confirmation Model (ECM) was used by Marikyan et al., to study smart home users’ technology adoption.<sup>54</sup> Some researchers are using a multimodel perspective which combines Technology Acceptance Model (TAM), Theory of Reasoned Action (TRA), and the Theory of Planned Behavior (TPB) models to understand usage intention of smart homes by the older adults.<sup>55</sup>

**Commercialized assistive technologies**

Assistive technologies can support older adults to lead an independent, safe and secure life within the comforts of their own home. Different types of assistive technologies, such as remote health monitoring via video, sensors and other smart objects, fall detectors, door monitors, bed sensors, and Smart HVAC (Heating, Ventilation, Air conditioning) which can support the aging community, have been previously defined by Miskelly.<sup>56</sup> Table 2 lists various examples of commercially available assistive technologies fitting within these categories and more.

Several studies show that older adults generally have a positive attitude toward the technologies mentioned in Table 2<sup>21,57–61</sup> but they raise ethical and technical concerns, such as: privacy,<sup>9,20,43,62–69</sup> autonomy,<sup>20,62,63,68</sup> beneficence,<sup>20,63,68</sup> loss of social contact,<sup>20,63,65,70</sup> ease of use,<sup>9,70</sup> control over technology,<sup>63,65,71</sup> support,<sup>63</sup> training or ability to learn,<sup>9,63,70,72</sup> lack of awareness,<sup>70,73</sup> personalization<sup>74</sup> and reliability.<sup>21,64,68</sup>

**Table 2.** Commercial products categorized.

Categories	Description
Smart Objects <sup>2</sup>	Objects connected via smart phones or laptops such as smart pillbox, door or smart locks. Also, for auto detecting presence such as for turning on lights.
Monitoring via Cameras <sup>3</sup>	Home security for older adults and activity monitoring.
Smart HVAC <sup>4</sup>	Smart heating, ventilation, and air conditioning for temperature control. Saving energy as well as providing control via smartphone.
Personal Emergency Response Systems <sup>5</sup>	Personal health monitoring system which can be used to call help in case of an emergency such as wearable push button necklace, watch, belts.
Smart Watch, <sup>6,78</sup>	Monitoring multiple measurements such as movement, falls, heart rate and SpO2.
Smart Phone Applications, <sup>9,1011</sup>	Reminders, step counts, data sharing with family members.
Sensors <sup>12</sup>	Monitoring activities and monitoring environment such as humidity sen sor, smoke alarm etc. Monitoring activities such as placed on the fridge, shower, pillbox, or any object to monitor that activity.

There are many more early stage research ideas being conceived than there are commercial products available for consumer use within the smart home technology space. Some examples of commercially available products are shown in Table 3. It could be argued that the steps involved in the commercialization of assistive technologies are slow or not able to meet consumer demands. Coughlin et al. discuss translation of invention to innovation stating that although assistive technologies have been available for some time, government and major corporations have only recently given priority to the implementation of technology for older adults community. Therefore, the availability of these assistive technologies may be limited due to the lack of the policies required to successfully convert them to commercial opportunity.<sup>64</sup>

## Findings

We organize our findings under two categories: (1) Ethical Considerations and (2) Technology Aspects. A summary of the findings from the surveyed studies is shown in Table 4.

### Ethical considerations

Ethics play an important role when developing any technology involving humans. This can heavily affect the adoption and acceptance of the technology if not considered. This gives rise to ethical and legal concerns despite the benefits that can be obtained from various assistive technologies.<sup>20,96–98</sup>

We have identified five themes related to ethical considerations including privacy, perceived benefits, autonomy, cost, and support of social and natural environments, stigma, social pressure, awareness and other issues.

<sup>2</sup>Tiny Logics, <https://pillbox.tinylogics.com>

<sup>3</sup>Arlo, <https://www.arlo.com/uk/use-cases/assisted-living/>

<sup>4</sup>Fibaro, <https://www.fibaro.com/en/smart-home-in-use/smart-hvac>

<sup>5</sup>Lifeline, <https://www.lifeline24.co.uk/>

<sup>6</sup>Medical Guardian, <https://www.medicalguardian.com/freedom/?aid=3900>

<sup>7</sup>MedicalFitbit, <https://healthsolutions.fitbit.com/>

<sup>8</sup>Garmin, <https://www.garmin.com/en-GB/>

<sup>9</sup>Red Panic Button, <https://itunes.apple.com/us/app/red-panic-button/id422029296>

<sup>10</sup>Blood Pressure Monitor, <https://apps.apple.com/us/app/blood-pressure-monitor/id430133691>

<sup>11</sup>Pillboxie, <https://apps.apple.com/us/app/pillboxie/id417367089>

<sup>12</sup>PPP Taking Care, <https://www.ppptakingcare.co.uk/>

**Table 3.** Current (smart home) assistive technology products and services.

Commercial Products	Description	Country	Cost Model
Lively <sup>13</sup>	Lively provides activity sensors which can be placed on common objects within a home for example pillbox, doors, fridge, keychain etc. It also provides a watch that includes a push but- ton for calling help in case of fall emergency. The watch can give reminders for medication, counts steps and shares this with family members.	US	Various upfront and subscription packages.
HomeCare <sup>14</sup>	Develco provides home monitoring sensors un- der the HomeCare umbrella, e.g., Gateway, Window sensor, Smart Plug, Light bulb, Flood alarm, Smoke alarm, Humidity sensor, Motion sensor for fall detection and preventing fire or any emergency. This is built for developers to design the solution.	Denmark	Individually priced sensors.
Geeni <sup>15</sup>	Geeni provides home monitoring sensors e.g., smart plug and switches, sensor alarms, smart humidifiers and various sensors.	US	Individually priced sensors.
Just checking <sup>16</sup>	Just checking is a home monitoring system to monitor movement of older adults by sensors attached to walls and various objects in the house. It is also for door monitoring and activity monitoring.	UK	Deposit with subscription packages.
CanaryCare <sup>17</sup>	Monitors movements, bathroom visits, tracks sleep, temperature and reminds medication.	UK	Various upfront and subscription packages
MariCare <sup>18</sup>	Smart floor and activity sensing for monitoring activities and falls.	Finland (with deployments in other countries)	Individually priced sensors
Smart Life in Fife <sup>19</sup>	Smart Life in Fife is a visual tool to aid people to manage their aging progress with expert advice.	UK	Free

### Privacy

Privacy is one of the major concerns voiced by participants in various studies.<sup>19,21,43,64,66,77,99,100</sup> In a focus group study about commercially available assistive technology products, participants raised a concern about the technologies monitoring them 24/7.<sup>64</sup> They considered it as a loss of dignity in their own home, even though they acknowledged that the purpose of the technology was to ensure their safety and security.<sup>64</sup> In a further study, participants stated that sharing details about them was very interfering and privacy intrusive.<sup>77</sup> They showed negative responses to image capturing technology which made them feel uncomfortable.<sup>101</sup> However, a recent study in the U.S. found that older adults with internet experience and a positive attitude toward emerging technology were willing to use Internet-connected cameras for home monitoring. Approximately 48% of participants were willing to use cameras for home monitoring compared to other technologies.<sup>92</sup>

They also mentioned that it was important for them to control information sharing as not all the participants were willing to share their data with their families, staff and health-care providers.<sup>77</sup> Participants in another study by Steele et al. stressed that they wanted systems to be unobtrusive.<sup>102</sup> Camera monitoring was found to be a useful method to provide complete activity monitoring and fall detection surveillance for older adults, but it was felt to be the most intrusive form of surveillance which made users feel more reluctant to adopt the system.<sup>103,104</sup> Interestingly, Birchley et al. mention

<sup>13</sup>Lively, <http://www.getmylively.com/>

<sup>14</sup>HomeCare, <https://www.developproducts.com/business-areas/home-care/>

<sup>15</sup>Geeni, <https://mygeeni.com/>

<sup>16</sup>Just checking, <https://justchecking.co.uk/>

<sup>17</sup>CanaryCare, <https://www.canarycare.co.uk/>

<sup>18</sup>MariCare, <https://maricare.com/en>

<sup>19</sup>SmartLifeinFife, <https://www.smartlifeinfife.org/>



**Table 4.** Key findings from assistive technology studies.

Author	Sample	Technology	Key Findings
Demiris et al. (2006) <sup>65,75</sup>	Focus Groups: 3 Male: 5 Female: 9 Total: 14 aged 65 and above Session Duration: 1 hour	Tiger place (Intelligent Ambient Living/Smart Home) which provides activity recognition data	Concerns related to privacy of data, social isolation, and lack of control over the technology were raised by participants, but they confirmed that the system was an independent unobtrusive way of living.
Demiris et al. (2006) <sup>65</sup>	Focus Group: 1 Gerontology Nurses: 4 Social Worker: 1	Tiger place (Intelligent Ambient Living/Smart Home) which provides activity recognition data	Visualization of large activity recognition data sets such as summaries and overall trends were thought to be more useful. Suggestions for designing the application to have consistent interfaces, allow communication with health care providers and interoperability with other applications for record keeping.
Rahimpour et al. (2008) <sup>76</sup>	Focus Groups: 10 Interviews with patients (congestive heart failure and/or chronic obstructive pulmonary disease) Location: Sydney Background: 7 different ethnic groups	Video and prototype demonstration of the a Home Telecare Management System (HTMS) by MedCare Systems Pty. Ltd. (Sydney, NSW, Australia)	The participants agreed that the technology could benefit their health, but concerns were raised regarding cost, usability, clinical support, inability to self-operate and anxiety issues relating to operating the system.
Coughlin et al. (2007) <sup>64</sup>	Focus Groups: 30 leaders in aging advocacy and aging services from 10 north-eastern states. Location: United States and Washington, DC	Commercially available and still under development technologies ranging from telemedicine systems, smart scales, health kiosk systems, personal advice systems to guide diet, home monitoring	Concerns regarding usability, privacy, reliability, and cost were identified, although participants acknowledged benefits of the technologies.
Courtney (2008) <sup>77</sup> Courtney et al. (2008) <sup>25</sup>	Focus Groups: 4 with 11 participants and 3 additional interviews Adults aged 65 and above Location: Mid-western U.S. residential care facilities	Smart Home technologies containing various sensor technologies such as bed sensor, kitchen sensor, motion sensor and fall detection sensor	The study found that privacy was the major concern which caused low adoption. But the need for these technologies could potentially override their privacy concern.
Dhukaram et al. (2011) <sup>21</sup>	Focus Groups: 5 Participants: 34 Location: West Midlands and Cheshire areas in England	BRAVE HEALTH System combining a wearable vital signs measurement system with telemedicine	Participants showed a positive attitude toward the benefits of the technology but were not willing to adopt the system due to current privacy, trust, reliability and security issues

*(Continued)*

Table 4. (Continued).

Author	Sample	Technology	Key Findings
Chernbumroong et al. (2010) <sup>78</sup>	Participants: 14 participants aged 26 to over 80 years old Location: Local hospitals, nursing homes and general population	A survey conducted to understand the perception of smart home technologies for assisting older adults	The participants showed positive attitude toward the six smart home technologies under review (cooking hob and oven safety control, sleeping pattern monitoring, emergency alarm, automatic lighting system, video monitoring system and activity monitoring system). However, willingness to adopt these technologies was uncertain among the participants. This could be due to factors such as difficult User Interface design, learning difficulties, privacy concerns, cost and lack of human responders.
Ziefle et al. (2010) <sup>15</sup>	Participants = 82 aged between 40 and 92 years. 53% male and 47% female 39/82 participants stated to have a chronic disease.	Questionnaire for smart technologies including smart homes, smart phones and smart clothing.	The study found no interrelation between age, gender or health status and willingness to adopt technology. Therefore, diversity (age groups, gender, health states) do not impact the acceptance of technology. The study also shows that smart homes were most critically evaluated compared to mobile devices or smart clothing. Also, participants gave less importance to the design and esthetic of the technology and more toward its beneficence.
Wilkowska et al. (2011), <sup>79</sup> Wilkowska et al. (2012) <sup>80</sup>	Questionnaire Participants: 104 Qualitative data evaluation Focus Groups: 1) n = 7 aged 24– 29 2) n = 6 aged 60– 68 3) n = 6 aged 67– 73 Quantitative data evaluation Focus Groups: 1) n = 25 aged 21– 29 2) n = 15 aged 30– 39 3) n = 21 aged 40– 49 4) n = 16 aged 50– 59 5) n = 16 aged 60– 69 6) n = 11 aged 70+	E-Health technologies e.g., blood pressure meter, blood sugar meter, insulin pump	The participants of all ages in this study perceive data protection and health and safety as highly important. Men tend to perceive greater advantages of health control using medical devices more than women. However, this is marginal difference only. Men also pay less attention to anonymous and intimate ways of using the technology, but other aspects of privacy seem to be similar in all gender groups. The study also shows that healthy people hold more importance for data protection, its storage and transfer for e-health usage than people with poor health. People with poor health tend to be less concerned about the permanent surveillance unlike healthy people.

(Continued)

**Table 4.** (Continued).

Author	Sample	Technology	Key Findings
Demiris et al. (2013) <sup>81</sup>	Focus groups: 2 Location: Seattle, Washington Participants: 12 older adults with average ages of 79.3 years 8 female and 4 males	Telehealth kiosk for assessing vitals such as blood pressure, weight, pulse oximetry and blood glucose	Participants perceived telehealth wellness kiosk as useful but many users said that staff assistance for using the system would be essential. Participants also liked the community aspect of the system and did not have privacy concerns using it. It was also discussed in the findings that peripheral devices need to be selected and designed with the user in mind. Ergonomics such as a mouse can be replaced by touch enabled devices and audio requirements can include headphones with adjustable volumes.
Reeder et al. (2013) <sup>82</sup>	Participants: 8 healthy adults aging 79 to 86 Location: Seattle, WA	A theory based monitoring study comprising of motion sensors, gateway (a hub or device which connects sensors to a server for data transmission) and data visualization.	Participants found the system to be unobtrusive, useful, with little to no privacy concerns and were interested in viewing their activity data. However, participants did not consider adopting the system as they considered themselves to be in good health.
Guo et al. (2016) <sup>74</sup>	Participants: 650 293 participants aged between 18 and 26 198 participants aged between 27 and 49 159 participants aged 50 and above Location: China	A survey of 650 participants with different age groups in China was conducted. This survey was conducted to study trust, privacy concerns and adoption intention for Mobile Health Services.	The study found that privacy concerns are associated with trust and intention of adopting the technology. While personalization is proportional to consumer trust and willingness to adopt. It also found that privacy is unlikely to be a problem for older adults which could be due to the lack of awareness about technology compared to young people.
Joe et al. (2016) <sup>83</sup>	Participants: 14 older adults aging 62 Focus Groups: 3 6 male and 8 females participants	Focus groups with participants were conducted about a wellness tool where they expressed various features which were desirable and undesirable to them.	Participants had a positive attitude toward the wellness tool but expressed privacy concerns and preferred to use a portable device which would be reliable and easy to use.
Hoque, R. et al. (2017) <sup>84</sup>	Participants: 300 participants aged 60 years or above	The study conducted a face-to-face structured questionnaire survey to determine factors impacting intention to adopt and use mHealth service technologies among older adults.	The findings show that social influence, performance expectation, anxiety related to using technology, and resistance to change had a significant impact on the intention of the older adult to use and adopt mHealth services.

(Continued)

**Table 4.** (Continued).

Author	Sample	Technology	Key Findings
Chung et al. (2017) <sup>85</sup>	Participants: 6 Korean American older adults Location: Seattle, WA	Motion sensors placed in home environment for monitoring daily activities	Participants generally found the system to be useful but expressed that it would only be beneficial to them in later life or due to health decline. They also raised concerns regarding privacy and obtrusiveness.
Chung et al. (2017) <sup>86</sup>	Participants: 11 Korean American older adults 10 Korean American older adults	Focus group and interviews conducted with older adults to understand perception of a home monitoring system for health. The home monitoring system includes features such as monitoring activity using motion sensors, temperature and door contact sensors, sleep monitoring, detecting falls etc.	Study found that many participants initially were not aware of sensor technologies but showed a positive attitude once it was explained to them. They expressed privacy concerns and were not comfortable using image capturing technology. Cost was also found as a barrier to adopting technology. But the need to live alone due to immigration or being away from family motivated the participants to be more accepting of the home monitoring technology.
Etemad-Sajadi, R. et al. (2019) <sup>87</sup>	Participants: 605 older adults who use health technologies.	The research focuses on older people's acceptance of healthcare technologies within their home.	The findings show that the usefulness of the healthcare technologies impacts older adult intentions positively and hence they agree to use them. Along with that, the social presence from using health care technology positively influences one's decision to use it.
Reeder et al. (2020) <sup>88</sup>	Participants: 10 female participants aged 60 or above.	The research studies perceptions of smart home and wearable technologies among older women. Technologies included fitness trackers, accelerator sensors, residential sensors such as bed sensors, activity sensors and video sensors.	Participants perceived sensors as acceptable for data collection of personal activities. Participants generally perceived wearable sensors more useful than smart home sensors as they mostly had activities outside their homes. While home sensors were considered most useful for those who spent their time mostly at home. Privacy concerns related to break-ins or unwanted disclosure of activity levels and overall had few concerns about data sharing.

(Continued)

**Table 4.** (Continued).

Author	Sample	Technology	Key Findings
Ashraf et al. (2020) <sup>89</sup>	Participants: Participants aged 55 year and above Location: Pakistan	Interviews covered perception of smart home technology among the Pakistani aged community.	About 91.5 percentage of the participants perceived smart technology as useful and convenient. However, it was found that excessive pressure from relatives and friends can easily hinder older adults from adopting technology. Issues with accuracy of technology can also negatively affect their adoption.
Shirani, F. et al. (2020) <sup>90</sup>	Participants: 24 residents aged between 20 to 70 years old Participants were interviewed once a year over a successive three year period Location: Caerau, South Wales Valleys	Interviews covered perception and experience of smart technology of low income house holders amongst vulnerable consumers.	Participants considered smart technology for vulnerable energy consumers to be beneficial for example remote controlled energy assistance for those with mobility impairments. Participants either showed interest in the new technology or found it wasteful. Participants under 40s considered it as 'cool' technology and perceived benefits of increased control while many of the older participants were less interested in it. This could be due to participants finding smart technology to be complex and unusable.
Pal, D. et al. (2020) <sup>44</sup>	Participants: 315 and 1945 participants in two phases Age range varied from 20s to 50s and above. Location: Thailand	Two surveys were conducted to study the adoption intention of the voice based smart home system.	Findings state that the senior people with high income and smart home appliances were most likely to use voice based smart home systems within an year. Participants with low intention of adoption perceived the technology to be less useful.
Marikyan, D. et al. (2020) <sup>54</sup>	Participants: 387 smart home technology users Age range varied from 18 to 65 and above.	A survey conducted to gather input about negative emotions and difficulties faced, from 387 smart technology users (for example smart security system, smart kitchen, visual assistant and many other technologies)	The findings state that people who experience negative emotions caused by a technology performance might cope by giving up the use of smart home technology.

(Continued)

**Table 4.** (Continued).

Author	Sample	Technology	Key Findings
Mashal, I, et al. (2020) <sup>39</sup>	Participants: 258 household Location: Jordan	This study investigates the reasons that influence people in Jordan regarding acceptance and usage of smart home services.	The findings show that trust, perceived usefulness, ease of use, enjoyment and personalization influence intention to use and technology adoption. Also, cost was found to be an insignificant factor to influence intention to use.
Nikou, S., Agahari et al. (2020) <sup>53</sup>	Participants: Interviews (N = 59) and Focus group (N = 12) sessions Electronic survey collected from older adults in Netherlands Follow up interviews (N = 7)	This research develops and tests a theoretical model to explain intention to use health technologies by older adults by considering how the digital health technologies enhance their ability to live independently.	Findings state older adults were positive about independent living and were against living in care settings. Participants mentioned difficulties faced by them to find the correct health care technology and service for them-self to live independently. Older adults base their intentions to use health care technology by assessing the capability of the products and service which enhances independent living.
Robinson, E. L. et al. (2020) <sup>66</sup>	Participants: Four Focus Groups of 23 participants aged 60 and above One Focus Groups of 5 participants with family members Five 90 Minutes Focus Groups	Focus groups were conducted to gather input from older adults and family members about adapting and using the home sensor technology	The findings state that family members were more eager to adopt the technology then older adults. Family members also expressed that they would want to have access to their older relatives health information despite them not wanting to obsess about their health. Participants of both groups did prefer using their cell phones to receives messages and health alerts. Older participants expressed concerns about privacy related to video monitoring.
Schlomann, A. et al. (2020) <sup>91</sup>	Participants: 1863 participants aged 80 to 103 years old Location: North Rhine-Westphalia, Germany.	The research studies about the adoption of assistive technologies among older adults in private homes and care facilities and analyses the environment and characteristics in both settings.	Mobile phones were most common among older adults living in private homes who did not receive any care. Assistive technology was found to be less common in private homes than in long term care. Information communication technology users were found to be younger, have higher level of functional health and were more interested in technology while users of assistive technology were older and had poor health comparatively.

(Continued)

**Table 4.** (Continued).

Author	Sample	Technology	Key Findings
Kadylak, T. et al. (2020) <sup>92</sup>	Participants: 1148 respondents aged 65 years and above Location: United States, America.	An online survey conducted through Qualtrics to assess willingness to adopt various emerging technologies including smart home technologies.	The findings show that older adults were most willing to use digital home assistants, smart technologies and Internet-connected cameras.
Guhr, N. et al. (2020) <sup>43</sup>	Participants: 187 respondents 100 males and 79 females and 8 unknown gender	The study explores and addresses information privacy concerns that affect usage intention of smart homes	The research found that privacy negatively impacts intention of use for smart home technology.
Weck, M. et al. (2020) <sup>93</sup>	Participants: Participants aged 55 years and above Location: 3 Finnish cities, Finland	Focus groups interviews were conducted to understand use of digital technology among aging people. The research presents findings on the basis of trust toward technology functionality, institution such as healthcare authorities in Finland and costs related to technology.	Findings suggest that generally, participants trusted digital assistive technology to work well but the healthcare service providers or authorities integrity and competence needs to be taken into account. Cost issues were also raised and that technology should be available for everyone equally.
Zou, P. et al. (2020) <sup>94</sup>	Participants: Participants aged 65 and above Chinese Immigrant Community in Canada Two groups-controlled trail with a sample size of 60 participants with high blood pressure Location: Ontario, Canada	A pilot study to design and test smart phone based dietary app for Chinese Canadian seniors to help with a healthy diet and hypertension control.	The research is in progress and aims to test the usability and feasibility of the dietary application to support Chinese Canadian seniors with a healthy diet and hypertension control. The research hypothesizes that this app will help decrease blood pressure and improve quality of life of seniors with elevated blood pressure.
Lin, T. et al. (2020) <sup>95</sup>	Participants: 35 Participants aged between 58 and 82 years old. Majority of participants were diagnosed with hypercholesterolemia and hypertension Location: Singapore.	Semi structured Interviews were conducted regarding ownership of mobile phones and its usage for healthcare to understand the willingness of adoption. Videos of mHealth applications were also shown to participants.	Participants considered mobile phones as a personal device and a way to access healthcare via calls and messages. It was identified that older adults face technology anxiety causing resistance toward adoption of mHealth applications. It was suggested that training can help reduce this anxiety and increase adoption of mHealth services and applications.

that users consider unobtrusiveness as an assurance of data privacy, suggesting that unobtrusive technologies could help alleviate some privacy concerns.<sup>105</sup>

Nonetheless, Demiris et al. report that older adults who evaluated the smart home “Tiger Place” at the University of Missouri (in Table 4) found it to be an unobtrusive environment but raised concerns about the

data shared with third parties.<sup>65</sup> In addition to data privacy concerns, it is also important to consider data protection. Sánchez et al. raise concerns regarding identity theft from a smart home. Since the smart home data contain details about a user’s behavior and daily routine, it becomes very crucial for this data to be protected.<sup>106</sup>

It was also found that privacy concerns seemed to be more important for younger people than older adults. This may be due to the lack of knowledge among older adults about the data transmission and other technical details involved in a system.<sup>74,97</sup> Studies show that compared to those in poor health, healthy people also hold more value to data protection, its connection with third parties, its storing process, and policies. People with poor health were more focused on how the technology can benefit them.<sup>79,80</sup>

Privacy being one of the main concerns among the participants could be overridden by a better understanding of the significant need for technology.

The need for the technology may lead people to adopt smart homes or assistive technologies if they fulfill their intended beneficial purpose. As mentioned above, people in poor health were more focused about the benefits of technology rather than privacy concerns.<sup>80</sup> We can conclude that the need for technology outweighs privacy concerns to some extent provided the expected or intended benefit is met by the assistive technology.<sup>77,99,106</sup> Despite this trade-off, older adults still require technology to be reliable and trustworthy. Guo et al.<sup>74</sup> found that privacy concerns are associated with trust, and they impact the intention of adopting the technology. For example, users not familiar with a given service provider are not willing to disclose their personal data for fear it will be misused, which in turn impacts the acceptance of service or technology. However, personalization and familiarization of the technology toward the user may positively impact users' trust in technology and therefore its acceptance.

A study conducted by Wilkowska et al.<sup>79,80</sup> found a gender difference when looking at various ethical aspects, including privacy. In this study, all age groups irrespective of health conditions deemed privacy to be of high importance. Only by a small marginal difference was noted; men seemed to be less concerned about the anonymous and intimate way of using technology while women were more concerned about the security and required more security features. Women are reported to prefer to use assistive technology in an anonymous way. To summarize, the main factors influencing views around privacy that these papers highlight are: obtrusiveness, camera surveillance, age, gender and personalization to improve trust. All age groups and genders are concerned about continuous surveillance and data privacy issues which creates doubts about adopting technology. Therefore, it is important to develop technology considering the privacy aspect as it may heavily impact the acceptance and adoption of technology.

### ***Perceived benefits***

Technology benefits are more evident to the caregivers<sup>107</sup> than to the older adults for whom the technology is designed. They feel they can do well without it, and therefore lack perceived benefit.<sup>107</sup> If the perceived benefit by the users is high, then they are more willing to adopt technology. Accordingly, older adults with high perceived benefit consider technology beneficial in supporting them for aging in a place and believe that technology will not only increase independence but also reduce burden on family and caregivers. This positive attitude toward the perceived benefits of technology helps in acceptability of the technology.<sup>108</sup> Therefore, it is important that the expectation of the users matched the benefits provided by the technology.

Systems should aim to deliver the benefits and functionality that users consider as desirable and avoid those which are not adequate or unnecessary.<sup>56,109</sup> For example, the basic need of the users expected from assistive technologies is to promote their QoL. In other words, users see a benefit in technologies that can support them to achieve daily tasks, maintain their health, provide safety, and enable independence. This can be achieved by designing systems that monitor health in an unobtrusive manner and alert contacts in case of emergency. These systems when connected to other e-health services can prove to be even more beneficial where doctors or GPs can be in touch with the user and monitor their health records.<sup>110</sup>

For assistive technologies to play an important role in supporting older adults they must be reliable.<sup>76,111</sup> One of the geriatric participants in a study reported failing to continue to use a blood pressure monitoring device as they felt readings were inaccurate.<sup>76</sup> Other functionality issues, such as batteries running out or malfunctioning of the features, cause older adults to distrust the devices,



making technology less appealing.<sup>63</sup> These occurrences take away the trust from the users, making it difficult for the systems to be adaptive.

There is some debate surrounding the factors affecting the adoption of technology. Wilkowska et al. found that men perceived the advantages of health control using medical technologies as more valuable than women did.<sup>79,80</sup> However, the difference is only marginal and perhaps this could be due to some women not perceiving the health technology beneficial for themselves due to no health conditions or perhaps lack of knowledge or simply marginal difference. It was found that males were more aware of IoT and the term "smart home" than females.<sup>73</sup> And, Zieffle et al. found that there was no relationship between diversity (age, gender or health status) and willingness to adopt technology.<sup>15</sup> Also, participants gave very little importance to the esthetic of the technology and were focused on the perceived benefits.<sup>15</sup>

Assistive technologies need to be designed with the expectations and requirements of users in mind. The system does not need to be highly complex to provide benefits otherwise it will make it difficult for users to operate and accept assistive technologies. For example, a remote health monitoring system should not require a complex set of commands to start up or interrupts activities of daily life (ADL), which makes it inconvenient for the user.

### Autonomy

Older adults may consider themselves as vulnerable due to their age-related health conditions. This does not imply that they do not have pride, self-respect, and dignity.<sup>96</sup> Studies show that some older adults think they will do well without assistive technologies as they feel ashamed and insulted.<sup>63</sup> They were not willing to wear devices to monitor their health as it would make them feel frail or needing special assistance.<sup>63</sup> Older adults also tend to prefer to live independently in the comfort of their own homes as long as possible.<sup>107</sup> Autonomy refers to this independence and control over one's life.<sup>112</sup>

Assistive technologies that restrict and restrain older adults may not be easily acceptable. For example, smart homes monitoring activities of individuals need to be adaptive of their habits and behaviors (daily routines).<sup>12</sup> Older adults tend to find it difficult to change their daily routine and learn new patterns and interactions for using the systems. Therefore, products should be designed to accommodate their existing living patterns rather than enforcing new patterns.<sup>107</sup> Technologies that do not offer users control, or limited control, over the influence on their lives are not readily adopted by older adults. For example, participants agreed that the sensors in the smart home (Tiger Place) were not intrusive but there was a lack of control, such as duration of monitoring, which made participants hesitate to adopt such technology.<sup>77</sup> Control over technology provides a sense of independence, making the user feel less conscious of being under surveillance as they can turn it off when they prefer.<sup>71</sup> The perception of control over a system made older adults feel they also had control over their well-being and, therefore, impacted their intention positively for using such a system.<sup>113</sup>

### Cost

Studies show that cost is a reason why older adults are reluctant to buy a technology<sup>19,64,76</sup> and it can also be difficult in rural areas, developing countries or countries with low economic development and low incomes.<sup>114</sup> Many business facilities have transformed to automated systems but very few households incorporate smart home technologies due to high cost.<sup>115</sup> Smart homes contain a collection of several sensors and technologies, making them costly. As older adults are often on a restricted pension income, cost can be an important concern as shown in a study by Steele et al.,<sup>102</sup> which highlighted cost as a frequently discussed subject in focus groups. They also found that older adults were more likely to accept the technology if the implementation and maintenance cost was covered by their children or the government.<sup>102</sup>

Since these technologies may indeed be costly, the concern about who will pay for these technologies become crucial. In case of care services, people with health insurance may have these costs reimbursed. But if people have to pay for assistive technologies, then the question of whether or how this will be available to people with low income is something that certainly should be considered.

Health is an important basic need for every individual. Services and technologies could either be made less expensive or at a subsidized cost for a more inclusive society, where not only the rich have access to these technologies. For example, government bodies could initiate methods to provide support to the community of older adults by making assistive technologies more inclusive through the improvement of their affordability and their integration with existing services.

### ***Support of social and natural environments***

Socializing is an important part of every person's life and depriving people from social needs can cause mental and physical health problems. Social support is a crucial environmental part which helps in improving health. Loneliness plays a role in increasing functional disability among older adults.<sup>116,117</sup> It is important to include social interaction using smart home technologies to help avoid loneliness.<sup>67,118,119</sup> Yeh et al. found a relationship between dependence on activities of daily life (ADL) and people who experience loneliness. Meaning people who were socially isolated or feeling lonely were more dependent on using instruments or assistance for completing daily activities of life.<sup>120</sup> A study by Chen and Chan found that factors specifically relating to cognitive decline, social isolation, and fear of illness were largely overlooked in studies relating to technology for older people.<sup>121</sup> It has been found that older adults perceive that smart homes restrict them from social interactions, which leads to loneliness. For example, the technology may give them a feeling of being safe only when within their house.<sup>65,122</sup> If technologies do not provide comfort and support maintenance of social interactions, this can lead to difficulties familiarizing with and learning to operate the technologies. This in itself can be a source of anxiety for older adults.<sup>63,122</sup> In light of the COVID pandemic, older adults and vulnerable groups have been enforced into social isolation. This isolation increases the risk of health decline, which creates a necessity for health-care monitoring with features to allow communication with family and friends and call emergency services in case of severe health decline.

### ***Stigma, social pressure, awareness and other issues***

There are several other reasons which cause low adoption assistive technologies.<sup>19</sup> Older adults participating in a study were not keen on using smart home sensors as they perceived it to lead to obsessing over their health. However, their family members thought the opposite and expressed interest in monitoring and accessing health information, despite the older adult not wanting to worry about it.<sup>66</sup> Another reason is the pressure from family and friends which can hinder their need to adopt technology by creating negative emotions.<sup>67,89</sup> When this motivation from friends and family is positive, it can lead to adoption of technology by older adults. This is also the case when their own need is higher than the pressure from others. However, if social and learning support is not available from the relatives, it could lead to discouragement, embarrassment, or impatience.<sup>89</sup>

Stigma can also lead to hesitation in adopting technology.<sup>97</sup> Another term for this could be Ageism which is a form of discrimination and discourages people from adopting technologies if they are told that this is specifically for frail, vulnerable and old aged people.<sup>123</sup>

Awareness, experience or low interaction with technology, ownership of devices (early adoption), and personality can also impact adoption of technology.<sup>73,89</sup> It was found that males were more aware of IoT and the term "smart home" than females.<sup>73</sup>

There is some debate around gender and adoption of assistive technology. Some studies show that older women seem to perceive technology as less beneficial than men in the same age bracket. This could be due to several reasons, one of which could be due to fewer female participants in the study or simply due to a marginal difference or a small sample.<sup>79,80</sup> Another reason for the gender gap in technology adoption could be simply due to societal influence. Older women had much lower access to employment and education than their male counterparts. STEM was less accessible to women in the past than it is today.<sup>124</sup>

A study was conducted in 2018 on smartphone acceptance and their usefulness among males and females in Jordan and the UAE. Generally, there was no difference in terms of how both genders think

about the significance of the ease of using smartphones. It was found that Jordanian females who were less exposed to smartphones perceived them to be less useful.<sup>125</sup> It shows that the gender gap varies due to cultural or social influence where women have less female role models to look up to, face sexism in education and at workplace, or simply have had less opportunities.

Women are more likely to withdraw from internet usage due to health and accidental barriers compared to men in a study on internet adoption among older adults.<sup>126</sup> Smart Home and other technologies do not involve diverse gender needs in research studies and products which can lead to less adoption than if these needs were considered.<sup>127–131</sup>

Prior research was gender biased and it historically led researchers to carry out their observations on males in biomedical, social, or behavioral research. This has resulted in the death of information focused on females ranging from organisms, well-being, governments, to polices.<sup>124</sup> This discrimination is no longer acceptable, and researchers recruit both genders to test and validate their developments. However, older generations of women may still be unaware of technology and its benefits that younger generations enjoy today.

This stigma and unawareness can be avoided by approaching older adults through media which is mostly used by them, for example, newspapers. Training or help portals and services can be provided to the aging, this will also give a sense of independence to them. Research shows that smartphones and watches seem to be more acceptable among older adults<sup>41,88,101</sup> while some also accept camera-based systems if privacy is taken into consideration.<sup>92</sup> This could be used to advertise service and technologies to assist them in their daily lives. Workshops, seminars and general awareness can be spread among people with the help of cell phones which will also help remove stigma if advertised appropriately.

### **Technology aspects**

Technology needs to be specially designed for use by older adults as they are more likely to suffer from various health conditions. Older adults can be less patient, have difficulties in learning new tasks, or have physical or cognitive problems. In a study by Steele et al.,<sup>102</sup> aged participants expressed their concern about interacting with wireless sensor network technologies due to not being able to use all functionalities of the system. Participants emphasized that systems can be difficult to understand due to their age. Hence, technology needs to be designed in a way which does not induce anxiety and discomfort and that it can be easily adaptable.

We have identified three themes related to technological aspects including user context and requirements, learning and training, and design and usability.

### **User context and requirements**

Despite the availability of various assistive technologies as shown in Table II, the rate of adoption is low. One of the reasons for this could be not understanding or stereotyping the users' needs and expectations<sup>132</sup> or simply not catering for the users' context and requirements. This makes the product less beneficial to the users and results in low acceptability and adoption. For example, some products are designed to be cost efficient for caregivers, instead of promoting the QoL of older adults.<sup>107</sup> It has been found that products currently available are not focused on the user's context and therefore do not consider the behavior, environment, or activities of the user. Systems need to provide information about the user's situation and environment to enable efficient remote monitoring and provide maximal benefit to the user,<sup>107</sup> whilst ensuring ease of operation for older users.

Understanding and catering for user requirements within this demographics are essential. For example, designing smart homes or intelligent environments where users have to alter their activities in accordance with the system, rather their own preferred way, should be avoided. Individual habits vary and forcing everyone to follow the same standards may lead to irritation since every individual is different. Therefore, it is important to design a system which adapts to individual needs.<sup>12</sup>

When designing a system for a specific audience, it must involve characteristics specialized to that user group.<sup>133</sup> For example, some older adults might have issues with reading small text on the screen, hence enhancing the font size, and creating interactive visualizations which are easily understandable is important. Overall, it is important to understand the audience at which the product is targeted, so it is more personalized and provides the perceived benefit, making it adoptable and acceptable.

### *Learning and training*

Older adults may have difficulty learning the new skills needed to interact with technologies due to their age and health conditions. This can result in difficulties when trying to accomplish regular activities of daily life. Hence, expecting them to learn and operate complex interfaces or configurations is not appropriate. Studies show that participants did not want to train or learn new technologies.<sup>64,76</sup> This causes fear, discomfort, and anxiety issues when trying to use such assistive technologies.<sup>19,63</sup> The aging community often regards technology as difficult to operate. Generally, they consider that they are not capable enough to learn new products.<sup>107</sup> Mostly, they agree that modern technology provides many benefits but because they consider themselves to be incapable of operating technology, they are hesitant to use and, therefore, benefit from it.<sup>121</sup>

Compared to young people, older adults have more difficulty in learning to use new products. However, this could be improved by making products with simple interfaces which are easy to use, and understandable to older adults.<sup>97,121</sup>

### *Design and usability*

Usability and design contribute to user experience, which indicates the level of ease of use, simplicity, and joy that a user can experience from interacting with the technology or product. It has been found that the ease of use, interaction with the device and controllability were the most important characteristics of a system among the middle-aged and older participants.<sup>15,71,134</sup> It is often assumed that a completely automated system might be easy to operate and interact with. Studies show that aged participants when given a choice between an automated and manual system, chose manual as it gives the feeling of having control over the system.<sup>42</sup> Systems may also create fear and irritation when a user is unable to control the system or interact with it.<sup>71</sup> Birchley et al. suggest that providing improper focus on choices to end users puts burden on individuals.<sup>105</sup> It was found that mobile health applications designed for people with dementia lacked some features, which impacted the user experience and its usage.<sup>135</sup>

There is some debate around the level of importance of design. Gamberini et al. found that 50% of the problems reported in technology by users were due to usability. This could be resolved by adjusting the design or providing training.<sup>136</sup> In contrast, Ziefle et al. found that participants were less concerned about the design of the technology. They were more focused on the benefits that the technology could provide.<sup>15</sup> The esthetic design of the technology is another perspective for designers and researchers to keep in mind when designing and developing assistive technology.<sup>88,137</sup> For example, older women in a study considered device esthetics as one of the barriers to wearable sensors and it was also found that the wearable sensors that were prominent were not acceptable.<sup>88</sup> Technology can be designed in a way which is familiar to the older generation, this enhances its sense of identity and belonging to the home environment of the person.<sup>137</sup>

Multimodal Interaction has also been found to be a positively evaluated technique for interacting with technology. This can include various interaction approaches, such as voice, keyboard, touch screens,<sup>138</sup> gestures,<sup>139</sup> or facial expression,<sup>140</sup> recognized by a system.<sup>138</sup>

Designing systems in a user-friendly and interactive manner is important. Older adults need to interact with systems that are easier to operate and provide appropriate feedback,<sup>66</sup> making them easier for users to comprehend.<sup>141</sup> Careful design is crucial as bombarding users with too many unnecessary options or heavy designs can complicate the system and negatively impact user perception of the technology.

### **Design and data bias**

Smart assistive technologies are being developed with the latest artificial intelligence (AI) to help their users achieve the full benefits of the technology. AI or machine learning uses training and test data to train and evaluate the systems. However, the data used to train the systems can be based on data sets which are nonrepresentative of the general case or the targeted audience. This creates bias which means the result is unjust for the audience which it is targeted toward.<sup>142–144</sup>

A study was conducted for face recognition algorithms with influence of factors, such as race, age, and gender. It was found that the accuracy of the system was lower for females people with darker skin color and varied among age groups as well.<sup>145</sup> Many studies mentioned in Table 4 include various age and genders but there is a difference in the number of recruited participants for age and gender. This variation can also lead to biased results, for example, a technology just reviewed and tested by males may not necessarily work for females or technology designed for older adults but tested by younger audience may also impact acceptance of technologies as they will not provide benefits as expected by its intended audience. A smart home study was conducted in a living environment where the residents were students and living at the Missouri University of Science and Technology Solar Village. The purpose of the study was to study about the use and interest in adopting smart home technology.<sup>146</sup> The research is a great way to understand the perspective of residents regarding smart home technology. However, the same study needs to be conducted with residents who are aged 65+ to understand their perspective for research aimed specifically for older adults. Another example is results achieved on gender difference. For example, there is some debate around difference in perception about smart home technology between genders. However, this could be either statistically insignificant (only marginal difference) or perhaps differences in sample sizes. There may be a difference in need between the genders or differential financial constraints or awareness.

Data sets are a crucial part of AI applications. They need be large and aligned to the population they are designed for.<sup>123</sup> Data set accountability is also essential when determining what is going to be used in an application.<sup>72</sup> Another example is of patients with dementia where providing care varies on an individual basis. This variation requires to be aware of the person's condition to be able to provide a comprehensive care. A behavior pattern based on an incomplete data set or on average values may not produce expected results and undermine the care.<sup>123</sup> Data can be collected from real environments and shared with hospitals and researchers over years to collect real data and experiment research on that.<sup>123</sup>

### **Recommendations**

Having surveyed the state of the art in assistive technology for smart homes, we are able to recommend that researchers and developers keep both the user needs and user experience in mind when designing an assistive system through: (1) Providing interfaces to control and configure the monitoring system with feedback for the user, (2) Designing a system which can easily integrate in daily life without creating any constraint or difficulties for the user, and (3) Defining clear and concise policies about data ownership enabling transparency and increasing trust.

Privacy seems to be one of the major concerns which initiates fear of technology leading to lack of trust. Older adults appear to prefer unobtrusive assistive technologies, which are designed to protect their dignity and independence. Privacy concerns can lead users to opt-out of using technologies, despite the benefits they offer to them. Hence, assistive technologies must ensure independence, dignity, choice of control over technology, and information sharing. Data ownership policies need to be introduced, this will include in Europe the General Data Protection Regulation (GDPR) or equivalent policies that may protect and help people understand about the data transmission, storage, and sharing with third parties. Data protection is also crucial for data obtained from smart homes as the risk of identity theft is high,<sup>106</sup> and thus poorly secured smart home systems may be vulnerable to such attacks. Therefore, excellent security protocol measures must be followed.

Personalization is an important factor which helps in earning users trust. Deriving the system around user's behavior and activities may enable the technology to be more adaptive to the needs of the older adult.<sup>74</sup> It is crucial to design technology in a way that provides informative visualization of data and with simple interfaces which boosts ease of use and ease of comprehension. It is assumed that intelligent environments are easier to use and control. However, a fully automated system may take away the control from the user, making them feel vulnerable to the system.<sup>71</sup>

Hence, providing users with a configuration panel to control the technology with appropriate feedback is necessary.<sup>113</sup> It can help improve the system if customer satisfaction feedback is taken continuously to improve the needs of the aged demographic. Study shows that older adults can be reluctant to adopting technology, which associates themselves as frail and vulnerable or has negative image of being too old attached to it. Therefore, self image should be taken into consideration when designing or marketing an assistive technology.

Products available are often standalone and are made independently of one another. Therefore, the integration or connectivity for exchanging information is limited.<sup>107</sup> For example, products defined in Table II and Table III cannot be connected to exchange information. Hence, the benefit is limited to each technology. Smart homes need to have devices that can communicate and exchange information, to provide meaningful data about the user and their environment. For this purpose, hybrid solutions need to be designed that contain a combination of various sensors and devices that communicate with each other. Systems need to be designed so that they comprise multiple functionalities to provide a solution under one platform. For example, giving users reminders in a visually friendly calendar, summarized data, trends, alerts, and information about the environment,<sup>12</sup> making technologies integrable, so they become part of the user's daily life rather than forcing people to change their routine.

## Conclusion and future work

Smart homes consisting of several assistive technologies provide a variety of benefits for older adults who want to live independently in the comfort of their own home and improve their QoL.

Older adults are often portrayed as dependent and resistant to change. However, they are demanding users who seek an independent and socially connected life. Studies show that though people are willing to use these technologies, factors such as privacy, perceived benefit, autonomy, cost, and support for social environment and technology aspects (user context, user requirements, design, usability, learning, and training) as highlighted in the findings of the extensively surveyed literature listed in Table 4 must be catered for when designing such systems. Customer satisfaction feedback can be utilized to help minimize these problems. This would help in improving the system design in accordance with user-specific needs, hence making it more adoptable. Trust needs to be gained by personalization and focusing on the needs of the user while incorporating ethical and technical aspects. Finally, the key themes we have identified that smart home technologies need to consider are: (1) provide intended or expected benefit, (2) data ownership policies and data security, (3) Personalized systems to gain trust, (3) high reliability, (4) cost effectiveness, (5) promotion of autonomy (independence and control over technology), and (6) caters for user requirements and enhances user experience.

Most importantly, older adults should be involved in the evaluation of these products as end users. If older adults are not aware of, or satisfied with the products, then it is highly unlikely that they will be willing to accept and adopt these technologies. We would, therefore, recommend that future research includes investigating the perception of older adults on currently available commercial products and getting early feedback on state-of-the-art research.

There is a need to study the current rate of adoption and acceptability of assistive technology among older adult people. Understanding the perception of available assistive technologies among older adults as illustrated in Tables 2 and 3, is essential. It is crucial to evaluate what older adults are expecting from smart homes and assistive technologies. This data could help design future



technologies to maximize the perceived benefits, acceptability, and adoption among the aging community.

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